THE DEVELOPMENT OF PHOTOGRAPHY IN ASTRONOMY.*

By EDWARD E. BARNARD.

At the beginning of the work of this Association, the great discovery of making pictures by the natural light of the Sun had just been made, and while it aroused a wide-spread interest all over the world at that time, there were few who dreamed of the great future value of photography in the arts and sciences. . . . It is especially gratifying to Americans that the first efforts to utilize the new discovery for the benefit of astronomy were made in this country.

Within less than one year from the announcement of DAGUERRE'S discovery, in March of 1840, Dr. JOHN W. DRAPER, of New York City, had succeeded in getting pictures of the Moon, which, though not very good, foreshadowed the possibilities of lunar photography. Five years later, the Harvard College Observatory may be said to have commenced its remarkable career of astronomical photography, when BOND, with the aid of Messrs. WHIPPLE and BLACK, of Boston, succeeded in getting still better pictures of the Moon with the 15-inch refractor. The next successes were due to the English astronomers, DANCER and DE LA RUE. The latter using a 13-inch speculum, without clock-work, made the most important of the early efforts at lunar photography.

In 1860, the subject was again taken up in America, this time by Dr. HENRY DRAPER, who, with a 15½-inch reflector of his own construction, secured photographs of the Moon superior to any previously made. These pictures of the Moon were the best taken until LEWIS M. RUTHERFORD began his remarkable work, about 1865. Using an 11-inch refractor, constructed under his immediate supervision—the first telescope corrected especially for the photographic rays—RUTHERFORD secured photographs of the Moon that have only been excelled in the past few years with the

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aid of such instruments as the 36-inch refractor of the Lick Observatory and the equatorial coudé at Paris.

But what is shown by the best lunar photographs has not yet approached that which can be seen with a good telescope of very moderate size. The minute details are at present beyond the reach of photography.

The first picture of the Sun seems to have been made on a daguerreotype plate by FIZEAU and FOUCAULT, in 1845. During the total eclipse of the Sun on July 21, 1851, a daguerreotype was secured with the Königsberg heliometer, by Dr. BUSCH, which appears to have been the first photographic representation of the corona. Photographs of more or less interest were secured at subsequent eclipses; but the first to represent the corona with real success was obtained at the eclipse of December 22, 1870, when the corona was shown on the plate to a distance of about half a degree from the Moon's limb. The eclipse of 1871 was still more successfully photographed, and an excellent representation of the corona, full of beautiful details, was secured.

All these pictures were made with the wet process; for the dry plate was not successfully used until about 1876, and it was five or six years later before it became generally useful or at all reliable.

In 1878, extensive preparations were made to observe the eclipse of July 29th of that year. Photography played an important part, though each astronomer also made the customary drawings of the corona. The comparison of the drawings with each other and with the photographs showed the utter inability of the average astronomer to sketch or draw, under the attending conditions of a total eclipse, what he really saw.

The closing of the year 1888 and the opening of 1889 brought one of the most important eclipses that had yet occurred from a photographic standpoint. Certainly no previous eclipse, nor any since, so far as that is concerned, was photographed by so many different persons, and with such a varied assortment of cameras, telescopes, etc. The path of this eclipse lay across Nevada and California, and every photographer, amateur or professional, near the line of totality, took part in the work. The amateur photographers of San Francisco and Oakland banded together under the leadership of Mr. CHARLES BURCKHALTER and photographed the eclipse in a systematic manner, the result being a most excellent collection of negatives of the corona. In some of these pictures the coronal streamers were carried to a far greater extent.

than at any previous eclipse; especially was this so in the photographs made by two of the amateur photographers, Messrs. LOWDEN and IRELAND. At this eclipse the lot fell to the writer to make the photographs for the Lick Observatory. But at this time the observatory had no instruments suitable for the work. To secure as large an image as possible with the poor equipment at hand, a 3½-inch visual objective, by ALVAN CLARK, was selected. This lens, after being reduced to one and three fourths of an inch in diameter and mounted in an oblong box, fastened to a polar axis driven by the clockwork belonging to the 12-inch equatorial, was found to give a fairly good photographic image. With this and two small photographic cameras nine negatives of the corona were secured. The best of these was one made with the CLARK visual objective. By extreme care in development, this negative not only showed the exquisite polar systems of streamers and the details of the corona close to the Moon, but also carried the coronal extensions a great distance along the ecliptic. This was by far the most successful eclipse, photographically, of any that had yet been observed, and forever set aside as worthless the crude and wholly unreliable free-hand sketches and drawings previously depended upon.

The eclipse of 1893 was successfully photographed in Brazil, Africa, and Chile. Professor SCHAEBERLE made arrangements for the photography of the corona on a large scale, and at Mina Broncés, Chile, secured a fine series of photographs. The image was formed by a stationary lens five inches in diameter, and with a focal length of forty feet, upon a large sensitive plate, which was moved by clockwork, to counteract the Sun's motion during the few minutes of the eclipse. In these pictures the image of the Sun was on such a large scale that the coronal details could be very accurately studied.

During the solar eclipse of 1896 the sky was cloudy at nearly all the stations, but a few photographs were secured. The most important one was that of the flash spectrum or the momentary reversal of the FRAUNHOFER lines which occurs just at the beginning and at the end of totality. This important picture, a triumph for photography, was made by WILLIAM SHACKLETON, a young Englishman, who, at the right instant, exposed a plate which caught for the first time the fugitive bright lines, which are only visible for about a second. At the recent eclipse, January 22, 1898, the photograph of the flash spectrum was repeated by many observers.

There is no question but JANNSEN, of Meudon, succeeded, many years ago, in making the best photographs of portions of the Sun's surface that have yet been made. This astronomer has always used the old wet-plate process, which seems to give the best results in solar work. One peculiar feature of these photographs is the frequent presence of blurred regions, in striking contrast to the generally exquisite sharpness of the granular surface. These disturbed regions are believed by JANNSEN to be due to actual disturbances on the Sun's surface and therefore to be true phenomena of the Sun. I have always had the impression that they are simply due to the presence of small areas of bad seeing which are passing at the moment of exposure; that is, they are the effects of small local disturbances in our own air, such as every visual observer is familiar with in night work. Doubtless, M. JANNSEN has long ago decided this question; but if so, it has escaped my notice.

Daily photographs of the solar surface are made at a number of observatories, principally at Greenwich, Kew, and in India, and, of late years, at the Lick Observatory. Thus a valuable record is kept of the changes taking place on the solar surface. One thing that this repeated and constant photographing of the Sun has proved, is the non-existence of the so-called intra-mercurial planets, which before the days of photography were so frequently seen transiting the Sun. Just as the photographic plate has accomplished this, so will it finally, when it has attained more perfection in dealing with the planets, show that many of the strange features ascribed to the surfaces of some of them do not exist.

At the eclipse of 1868, JANNSEN and LOCKYER found that the visibility of the solar prominences did not necessarily depend upon a total eclipse of the Sun; they found that by the aid of the spectroscope they could be seen at any time. This suggested to Professor YOUNG the idea that they might also be photographed at any time; and in 1870 he met with partial success in such an attempt. To photograph those objects successfully, however, required the invention of a new instrument, the essential features of which are two slits (very narrow, compared with the height of the prominences), moving in perfect unison — one placed across the Sun in front of the grating or prism, the other in front of the photographic plate — and adjusted perfectly to the spectral line of the prominence, so as to exclude all light save that emitted by the prominence itself. By the gradual motion of these two slits,

the entire object is successively uncovered, and an exact photograph secured of it. To make one of these pictures takes several minutes of exposure. This extremely ingenious device owes its existence to the inventive genius of Professor HALE, who devised and built the first instrument of this kind, and secured the first actual spectroscopic photograph of the prominences. This was in 1891. By a further ingenious extension of the possibilities of the instrument, it is made to move across the entire Sun's disc, thus securing every prominence at that time visible. By hiding the Sun's image by an occulting disc in the first sweep, and then making a second similar but more rapid sweep with the Sun's image uncovered, a complete picture of the Sun, with all its surroundings, with the exception of the corona, is secured. This is the method employed by Professor HALE in his work. These pictures, however, show only those features which are due to hydrogen or calcium, and the solar surface thus appears very different from the telescopic view of it.

From the first photograph of a star, by BOND, in 1850, to the present time, stellar photography has gradually risen to a prominence as remarkable as it is important. The real increase of importance, however, has occurred within the past ten or fifteen years, since the successful introduction of the very rapid dry plate. The wet, or collodion, process was poorly adapted to the photography of the stars, and of no use whatever for comets and nebulæ.

Notwithstanding this, the photographs of the star-clusters, etc., of the southern skies obtained under the direction of GOULD with an 11-inch photographic refractor, by the wet process, were of the highest value, and showed upon measurement a striking agreement in accuracy with visual work. The same can be said of RUTHERFORD'S photographs of the *Pleiades*, *Præsepe*, etc., which were made prior to Dr. GOULD'S, and which were the first photographs of this kind.

Attracted by its great brilliancy, Dr. GILL, at the Cape of Good Hope, with the aid of a local photographer, secured a fine series of photographs, with dry plates, of the great comet of 1882. When these photographs reached the northern hemisphere, they attracted a great deal of attention, not only on account of the comet itself, but also from the number of stars that were impressed upon the plates. The idea at once occurred to the HENRY Brothers, who were making a chart of the stars along the ecliptic in their search for asteroids, that they could use this wonderful

process in their work. To this simple incident the active application of stellar photography of to-day is due. They began at once the construction, with their own hands, of a suitable photographic telescope of thirteen and a half inches in diameter. This instrument was soon finished, and the astronomical world knows to-day what wonderful results these men produced with it.

Singularly enough, the photographic plate not only did away with the necessity of making charts by eye and hand to facilitate the discovery of asteroids, but it also did away with the necessity of the charts themselves for that purpose; for the little planet now registers its own discovery, by leaving a short trail on the photographic plate. The first of these photographic discoveries of asteroids was made by Dr. MAX WOLF, in 1892. They are now found wholesale in this manner.

It was the success of the HENRY Brothers' work that led to the International Astro-Photographic Congress which met in Paris in 1886. The Congress adopted the HENRY Brothers' lens as a model for the instruments to be used, and the work of this great undertaking was based on that of the HENRY Brothers.

Perhaps the most unpromising subject for the photographic plate to deal with was the nebulæ, and yet it is in this direction that photographic astronomy has most decidedly excelled. From September, 1880, when Dr. HENRY DRAPER secured the first nebular photograph the work of DRAPER, JANNSEN, COMMON, ROBERTS, and others has steadily advanced our knowledge of the structure and true outlines of these wonderful objects, revealing details — and even, as in the case of the *Pleiades*, streams and masses of nebulosity beyond the reach of existing visual telescopes.

While it is absolutely necessary to use a considerable photographic telescope for the accurate registration of star-positions, etc., where measures of precision are required, there are a great number of objects in the sky which are not necessarily subject to measurement, and which for their greatest value require a simple pictorial representation. The Milky Way, one of the most beautiful, and certainly the most stupendous, of the celestial features, is not susceptible of accurate measurement. Nor would the work be of any very great importance could it be accomplished as a whole. What is required in the study of this wonderful object — this mighty universe of stars — is something that

will increase the penetration of our vision, and at the same time give us a certain amount of accuracy of position with a large field of view, so that we may study its peculiarities of structure in detail, and at the same time closely locate these details with reference to the whole; and thus, by finally putting structure and detail together, form a comprehensive idea, not only of the details themselves, but also of the relation of these features to each other. The long-focus telescope with a very limited field is not capable of dealing with the Milky Way in the manner stated. Its structural details are very large, far larger in general than is the field of view of the ordinary photographic telescope, and vastly greater than that of a powerful visual telescope. We want, therefore, a short-focus instrument, one capable not only of taking in a wide part of the sky, but also of giving a brilliant image, or, in other words, the reduction of the large details to a smaller scale with a correspondingly great increase of effective light-power. These conditions exist in the large portrait-lenses which were needed in the early days of photography to reduce the exposure time by collecting a great quantity of light from the object, and which in these days of rapid dry plates are no longer required for portrait work. Taking in some ten or twelve degrees of the sky, these lenses are specially suitable for photographing large surfaces such as are presented by the Milky Way.

This subject was taken up by the writer in the first part of 1889, at the Lick Observatory, with a large 6-inch portrait-lens of thirty-one inches focus, and with it was inaugurated the photography of the Milky Way. The first picture to show the real structure of the Milky Way was made in 1889, with this instrument. In the following years a large series of photographs of those portions of the Milky Way seen from the northern hemisphere was made. The work with similar instruments was next taken up by Dr. MAX WOLF, in Germany, who has also succeeded in making excellent pictures of the Milky Way. Mr. RUSSEL, of Sydney, New South Wales, has also photographed portions of the southern part of the Milky Way with a large portrait-lens. Those who have seen some of the Milky Way photographs taken with the regular astro-photographic telescope, or who have tried to make out its complex structure with a visual telescope, must be struck with the great beauty of a photograph made with one of these short-focus portrait-lenses. The extraordinary complexity of structure of the Milky Way is brought

out with marvelous beauty of detail, and the peculiarities of its different portions can be traced and connected in the different photographs, which thus afford the most direct means for studying every feature of structure and detail. These pictures show many peculiarities which must materially alter our ideas of the constitution and structure of the Milky Way. Some of them show strong evidence that the general body of the Milky Way may be made up of small stars which are not at all comparable with our Sun in dimensions. This is especially shown in the region of the star *ρ Ophiuchi*. Many parts of the Milky Way appear to be comparatively thin sheetings of stars, with relatively no very great depth; for it is not possible otherwise to explain the black holes and rifts shown in them. One of the most important revelations made by the portrait-lens in connection with the Milky Way, is the presence in it of very diffused nebulous matter, apparently freely mixed with the groundwork of stars, and seemingly showing no definite tendency to condensation about the individual stars. These photographic nebulosities of the Milky Way are apparently of a different nature from the ordinary nebulæ of the sky, since they are extraordinarily large, diffused, and but feebly luminous. These nebulous regions seem to be peculiar to the Milky Way and its vicinity, and are certainly in some way physically connected with it. It will be in the study by photography of such regions that we shall finally clear away some of the mysteries of the Milky Way. These masses of diffused nebulosity mainly affect regions of the sky in *Scorpio*, *Cygnus*, *Cepheus*, *Perseus*, and *Monoceros*. I believe it to be true that no other form of telescope but the old-time portrait-lens, or similar combination, is capable of dealing with these extraordinary objects.

It was not until the study of the phenomona of comet-tails with portrait-lenses that we knew anything of the strange phenomena shown by them. It may be said that our knowledge of the extremely rapid transformations in the tails of comets dates from the photographs of SWIFT'S Comet of 1892, taken at the Lick Observatory with the lens previously mentioned, and by Professor PICKERING, at Arequipa, with a similar instrument. While only an insignificant affair visually, and but fairly visible to the naked eye, SWIFT'S Comet showed upon the photographic plates the most extraordinary and rapid transformations yet seen in any comet. One day its tail would be separated into at least a dozen individual streams, and the next present only two broad stream-

ers, which a day later had again separated into numerous strands, with a great mass, apparently a secondary comet, appearing some distance back of the head in the main tail, with a system of tails of its own. This remarkable appearance was the first known of its kind, though it was repeated in the photographs of RORDAME'S Comet of 1893, made by Professor HUSSEY. These peculiar phenomena seem to be a production of the comet itself—a result of the forces at work in the head of the comet.

The photographs of BROOKS'S Comet of 1893, also secured with the WILLARD lens, showed such an extraordinary condition of change and distortion in the tail as to suggest some outside influence, such as the probable collision of the tail with some resisting medium, possibly a stream of meteors, such as we know exist in space. The long series of photographs obtained of this comet frequently showed great masses of cometary matter drifting away into space, probably to become meteor swarms. One of the pictures showed the tail of the comet streaming irregularly, as if beating against a resisting medium, and sharply bent at right angles near the end, as if at that point it encountered a stronger current of resistance. All of these wonderful phenomena would have been unknown to astronomers had it not been for these photographs, and the comet, instead of proving to be one of the most remarkable on record, would have passed without special notice. Though these phenomena were so conspicuously shown, scarcely any trace of the disturbance was visible with the telescope. On account of the apparent insignificance of the comet visually, no photographs were made of it elsewhere during its active period.

In the matter of discovery, the photographic plate has accomplished a very great amount in certain directions. In spectroscopic work, it has a field singularly suited to display its possibilities, and the most important researches in this direction are now conducted by this means. The discovery of variable stars by photography can be compared with the wholesale business in commercial circles, because of the great numbers that are found on the various plates.

In the discovery of nebulæ and asteroids the photographic plate has done a great work, which is still being carried on.

Up to the present time but two comets have been discovered by photography. The first of these was discovered on a photographic plate taken by the writer on October 12, 1892, with the 6-inch WILLARD lens of the Lick Observatory, and was subse-

quently verified visually, and observed at different observatories. The second was discovered at the same observatory by Mr. CODDINGTON, with the same instrument, in July, 1898.

There are very few departments of astronomy where photography has not taken a prominent, if not a commanding, position. It is probable, however, that it will never take the place of the micrometer in the observation of close double stars and similar objects, and in this direction the micrometer of BURNHAM will perhaps never be displaced. The photography of the surface features of the planets is in an almost hopeless condition at present, yet much can be expected in this direction when an increased sensitiveness of the plates has been secured.

It is impossible within the limits of this address to give more than a general, and at best incomplete, sketch of the rise and progress of photography in the various lines of astronomical research. To those who have kept pace with these rapid strides in the last twenty years, this brief history will seem imperfect, and perhaps of little interest. Many applications of the photographic art, and many valuable results have necessarily been omitted. But few of the names of those prominently identified with this subject have been mentioned, and but little of their work even alluded to. A volume of no small dimensions would be necessary to give a complete history of the development of photography in the many directions in which it has been applied to astronomy. The time to do this has not yet come. Progress has been so rapid and far-reaching that its history, however complete and exhaustive, a year later requires to be rewritten; and there is no reason for supposing that the end, or even the beginning of the end, has been reached. With new materials, and new methods, and new workers, who will profit by the experience and results gained by those who have in our time accomplished so much, we may expect for the new century far greater results than those briefly recorded here.

THE SURFACE OF THE SUN.

By ROSE O'HALLORAN.

The following data, obtained from records of the condition of the solar surface as observed with a four-inch telescope, seemed to indicate the near approach of the sun-spot minimum.